Sensor, User, Mission (SUM) Resource Management and Their Interaction with Level 2/3 Fusion

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Abstract – Revisions to the JDL model by the current DFIG team (Data Fusion Information Group) include definitions for model usefulness that stressed various control functions of sensor, user, and mission (SUM) management. The purpose of the paper is to highlight issues and challenges to real world separation of control actions. This position paper highlights:

1. Addressing the user in system management / control,
2. Determining a standard set of metrics for optimization,
3. Evaluating fusion systems to deliver timely info needs,
4. Dynamic updating for planning mission time-horizons,
5. Designing interfaces to support impact assessments

Keywords: *Fusion, Situational/Impact Assessment, Resource/Sensor Management, User Refinement*

1 Introduction

In the companion paper, we listed many of the issues and challenges in Situation Assessment (SA – Level 2) [1] for knowledge representation and reasoning. In this paper, the goal is not to reiterate many of the issues and challenges of SA, but to build on these as related to specifically Level 3 (Impact Assessment) and Level 4 (Process Refinement).

Hall and Llinas [2] address various surveillance volumes and for sensor platforms (e.g. *Battlefield Intelligence*, 10s to 100s of miles, aircraft). In Level 4, they list the key techniques of *Measurement of evaluation*, *Measures of performance*, and *Utility theory.* The issues and challenges listed for Level 4 processing from 1997 are:

Current Status	Challenges/ Limitations
Robust single sensor	Incorporation of mission objectives
Operations research formulation	Environmental context for sensor utilization
Limited approximate reasoning app.	Conflicting objectives
	Dynamic algorithm selection
MOP / MOE focus	Diverse sensors

The key challenges expressed were (1) limited communications bandwidth for data aggregation, (2) context-based approximate reasoning for Level 3 understanding, and (3) knowledge representation for Level 2 processing. While many of these issues are consistent with the *ISIF05 panel* discussion for SA processing [1]; the key metrics for evaluation have not been adopted by the community. Since 1997, more timely and localized information is needed for individuals carrying a hand-held video cell phones. The interplay for Level 4, *Resource Management* (RM) and the various fusion process levels are still evolving as more data is available. [3]

In this paper, we address briefly the issues associated with resource management for Level 2/3 (SA/IA) interaction. [4] As stated above, while SA and IA are less well researched, even further removed is the SA-RM and IA-RM interdependencies. Developments for tracking and control (Level 1/4) have been addressed [5,6], and communication issues. [7,8] Also, utility and risk assessments [9] have been posed for SA/IA interactions that could be used in an objective function. What is missing from previous research is that the *Users* drive the control process, from the inception of sensor designs to fusion algorithm approval.

The rest of the paper will focus on issues and challenges for SUM management as related to level 2/3 processing. Section 2 explains the DFIG model. Section 3 discusses level 2/3/4 assessments and Section 4 discusses issues for resource management.

2 DFIG Fusion Model

To set the stage, we again show the DFIG 1 (Data Fusion Information Group) model (as the upgrade to the JDL [10, 11] model), shown in Figure 1. In this model, the goal was to separate the information fusion and management functions.

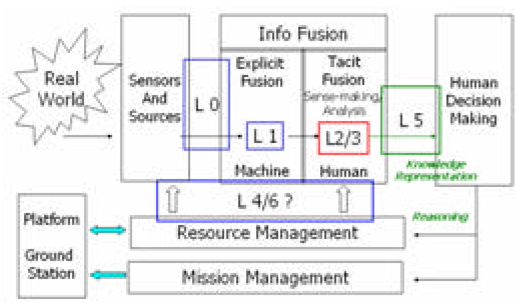

Figure 1. DFIG 2004 model.

The key in the DFIG model is to realize that differing control functions are based on the spatial / temporal / spectrum difference. The *spectral* needs are based on the type of sensor needed. The *temporal* needs are based on the user's need for timely information to afford action. Finally, the *spatial* needs are based on the mission goals.

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[1] Frank White, Otto Kessler, Chris Bowman, James Llinas, Erik Blasch, Gerald Powell, Mike Hinman, Ed Waltz, Dale Walsh, John Salerno, Alan Steinberg, Dave Hall, Ron Mahler, Mitch Kokar, Joe Karalowski, Richard Antony

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUL 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE **Sensor, User, Mission (SUM) Resource Management and Their Interaction with Level 2/3 Fusion**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Research Lab,2241 Avionics Circle,Wright Patterson AFB,OH,45433**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
9th International Conference on Information Fusion, 10-13 July 2006, Florence, Italy. Sponsored by the International Society of Information Fusion (ISIF), Aerospace & Electronic Systems Society (AES), IEEE, ONR, ONR Global, Selex - Sistemi Integrati, Finmeccanica, BAE Systems, TNO, AFOSR's European Office of Aerospace Research and Development, and the NATO Undersea Research Centre.

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Management functions are divided into sensor control, platform placement, and user selection to meet mission objectives. SA includes tacit functions which are inferred from level 1 explicit representations of object assessment. Since the unobserved aspects of the SA problem can not be processed by a computer, user knowledge and reasoning is necessary. Level 3 (IA) sense-making of impacts (threats, course of actions, game-theoretic decisions, etc) helps refine the SA estimation and information needs. The current DFIG definitions include:

Level 0 – Data Assessment: estimation and prediction of signal/object observable states on the basis of pixel/signal level data association (e.g. information systems collections);

Level 1 – Object Assessment: estimation and prediction of entity states on the basis of data association, continuous state estimation and discrete state estimation (e.g. data processing);

Level 2 – Situation Assessment: estimation and prediction of relations among entities, to include force structure and force relations, communications, etc. (e.g. information processing);

Level 3 – Impact Assessment: estimation and prediction of effects on situations of planned or estimated actions by the participants; to include interactions between action plans of multiple players (e.g. assessing threat actions to planned actions and mission requirements, performance evaluation);

Level 4 – Process Refinement (an element of Resource Management): adaptive data acquisition and processing to support sensing objectives (e.g. sensor management and information dissemination).

Level 5 – User Refinement (an element of Knowledge Management): adaptive determination of who queries information and who has access to information (e.g. information operations) and adaptive data retrieved and displayed to support cognitive decision making and actions (e.g. human computer interface).

Level 6 – Mission Management (an element of Platform Management): adaptive determination of spatial-temporal control of assets (e.g. airspace operations) and route planning and goal determination to support team decision making and actions (e.g. theater operations) over social, economic, and political constraints.

Issues

1) Level 2/3 tradeoffs in information quantity (*throughput*)
2) *Timeliness* of level 3 process refinement to control sensing needs (e.g. parameters to sense)
3) Level 3 use of *domain knowledge* to predict future sensing needs (i.e. context)
4) Multiple users have differing levels of process needs in a *distributed fashion* from the same situation.
5) Varying *fidelity of confidence* reporting of impending threats and situations

Challenges

1) *Pedigree analysis* to backtrack through associations to capture the impending threat
2) *Time Horizons of control* actions from IA to update the SA (i.e. priority schemes)
3) *Performance models* of level 1 analysis to afford level 2/3 information needs satisfaction and sensor management
4) *Hierarchical cost functions* that include risk and utility analysis of level 4 processes.
5) Unified *set of metrics* that afford level 2/3 processing that can be optimized in a level 4 objective function

3 Level 2-6 Functions

Level 2/3 (***situation assessment*** / ***impact assessment***) issues resolve around a bottom up or top-down analysis. SA desires as much local/ global information (bottom-up) [**12**] to increase spatial and temporal coverage [**13**], while IA is interested in dimensionality reduction (top-down) for action. IA is concerned with the retaining salient information through filtering. [9, **14**] IA filters pertinent past information, estimates and prioritizes intent [**15**], or predicts consequences. An example is a risk analysis, which uses utility theory to determine the potential impact of a situational state. Another analogy might be the breath versus depth analysis. SA is searching for information (*breath*) while IA is linking together for a time-chaining of events (*depth*). For varying levels of threats, there are: (1) Mission Area, (2) Awareness, and (3) Individual Awareness Boundaries.

Level 4, ***Process Refinement***, includes **sensor management** control of sensors and information. In order to utilize sensors effectively, the IF system must explore service priorities, search methods (breadth or depth), and determine the scheduling and monitoring of tasks. Scheduling is a control function that relies on the aggregated state-position, state-identity and uncertainty information for knowledge reasoning. Typical methods used are (1) objective cost function for optimization, (2) dynamic programming (such as NN methods and reinforcement-learning based on a goal), (3) greedy information-theoretic approaches [6], or (4) Bayes net which aggregates probabilities. Whichever method is used, the main idea is to reduce uncertainty, detect events, and afford mission planning. With many possibilities for PR, the user must agree to the strategy embedded in the sensor management control function.

Level 5, ***User Refinement***, functions include the (1) selection of models, techniques, and data, (2) determining the metrics for decision making, and (3) performing higher-level reasoning over the information based on the user's needs. The user's goal is to perform a task or a mission. The user has preconceived expectations and utilizes the level 0-4 capabilities of a machine to aggregate data for decision making and mission completion. For example, the user plans ahead (forward reasoning) while the machine is reasoning over collected data (backward reasoning). If a delay exists in the IF reasoning, a user might deem it useless for planning.

Level 6, ***Mission Management*** functions include the (1) addressing the cost and maintenance of platforms, (2) determining where to place assets, and (3) coordination of the operators of the sensors and platforms. The User is a team that responds to some need that plans a mission (sensor, platforms, time-on-station, look angles, etc). The mission determines the team, which instantiates the actors (i.e. users) as a subset of the group, from which platforms with sensors are fueled with communication bandwidth allocations, and set in motion for predictive sensing.

4 SUM Issues

4.1 User Control

The key for RM is to understand how the user reasons for action based on IF results including *trust*, *workload*, and *attention* [4] and perceptual needs. [16]. The roles that the user can play include *planning*, *organizing*, *coordinating*, *decision* and *action*. Kokar [17] and others [18] stress ontological and linguistic questions concerning the user interaction such as semantics, syntatics, efficacy, and spatio-temporal queries.

4.2 Standard Set of Metrics for Evaluation

Designing complex and often-distributed decision support systems (data → information → decisions → plans → actions) requires an understanding of both the fusion and user processes. DM requires: (1) SA/IA, (2) dynamic responsiveness to changing conditions, and (3) continual evaluation to meet ***information needs***. [19] Important aspects of fusion include timeliness, mitigation of uncertainty, and output quality relative to contexts, requirements, and constraints. Standardized *absolute and relative assessment* metrics for evaluating the success of deployed and proposed systems must map to these constraints for reliability/integrity through verification and validation tests. Many IF strategies must be rigorously evaluated by a standardized method over various locations, changing targets, differing sensors, and IF algorithms. [2] Issues must involve as well as local and global metric optimization in RM including: [20]

Table 2: Metrics for various Disciplines.

COMM	User	Info Fusion	ATR/ID	TRACK
Delay	Reaction Time	**Timeliness**	Run Time	Update Rate
Prob. Error	Confidence	**Confidence**	ROC	Prob. Detect
Delay Var.	Attention	**Accuracy**	Pos. Accuracy	Covariance
Throughput	Workload	**Throughput**	No. Images	No. Targets
Security	Trust	**Reliability**	Authorize	Cooperative
Cost	Cost	**Cost**	# platform	No. Assets

4.3 Timely Information

Fusion evaluation requires off-line and on-line assessment of individual sensor and integrated sensor exploitation (i.e. *performance models*) so as to plan a mission and react in a timely manner. Mission management requires putting platforms with sensors on station at the correct time, preparing operators, and determining pending actions with estimated data.

When tasked with an SA/IA analysis, a user can respond by one of three manners, broadly: reactive, proactive or preventive. In a ***Reactive mode***, the user makes a rapid detection and minimizes damage to *immediate threats*. The individual user selects the immediate appropriate response (in seconds) with aid of sensor warnings of threats. In the ***Proactive mode***, [21] the user utilizes sensor data to anticipate, detect, and capture needed information prior to an event. A Multi-INT sensor system could detect and interpret anomalous behavior and alert an operator to *anticipated threats* in minutes. The mode that captures the entire force over a period of time (i.e. an hour) is the ***Preventive Mode***. The preventative mode includes an Intel database to track events hours before they reach deployment for mission management.

4.4 Distributed, Dynamic Updates for Planning

Intelligent decision making requires distributed, dynamic and timely updates. Standard models, such as the Observe-orient-decide-act (OODA), estimate individual user's planned, estimated, or predicted actions. Assessing susceptibilities and vulnerabilities to detected, estimated, and predicted adversarial threat actions, in the context of planned courses of actions, requires a concurrent timeliness assessment and its affects on team decision making. Such assessment is required for adequate distributed actors, yet is not easily attained.

Coordinated complementary and orthogonal actions are needed over differing timelines and geographical areas. Mission management needs address *global control* functions that helps to determine which sensors and users are activated in for *local control* responsibilities and action approval.

4.5 User Display for Interaction

Fusion models process data for user decision making. The top-down approach explores an information needs pull by queries to the IF system (*cognitive fusion*), while a bottom-up approach pushes data combinations to the user (*display fusion*). The main issues for user-fusion interaction is the query ontology, understandable metrics, and uncertainty [22] and dimensionality reduction.

An inherent difficulty resides in the fusion of only two forms of data with *conflicts*. Sensor conflicts increase the cognitive workload and delay action. However, if time, space, and spectral events from different sensors are fused and displayed, conflicts can be resolved with an emergent process to allow for user refinement over varying perspectives. Displays give the user a global and local SA/IA to guide attention, reduce workload, increase trust, and afford action. A formal ***Fusion Usability Evaluation*** (*user-centered* or *user-driven*) is needed to define process interactions for users to complete their tasks.

5 Summary

This paper provides insights into user *information needs* from situation/impact assessment for sensor, user, and mission (SUM) management. The DFIG supports effective and efficient proactive decision making. Information fusion SUM issues, are (1) designing for users, (2) determining a standard set of metrics for cost function optimization, (3) evaluating systems to support effective decision making, (4) requiring decentralized updates for mission planning, and (5) fusion interface guidelines to support user's control actions.

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